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THE RELATIONS BETWEEN SCIENTIFIC BOTANY AND PHYTOPATHOLOGY

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The ever-increasing importance of phytopathology is the result of the steady development of agriculture, forestry, and horticulture. In this way phytopathology has become a part of each of these sciences.

In former times well-known botanists, such as Gleditsch, Martius, Caspary, de Bary, and Sachs did not estimate themselves too highly to concern themselves at times with phytopathological problems. In modern times, however, it is not often that a university professor of botany occupies himself with such problems. This is due partially to the specialization which has become a necessity in modern science. Above all, however, this is due to a peculiar conception which looks upon the applied branches of applied natural science as something inferior to the pure natural sciences. It must, however, be said that we find exceptions even here, if we think of such scientists as Brefeld and De Vries.

Agriculture has within a short time presented many problems to phytopathology, and of these the principal ones have been those of disease control. These problems were often solved in a hasty way, which, I must admit, lacked scientific thoroughness. But even in the solution of these problems many interesting facts were brought to light. But with the progress in working out these questions it became more and more evident that many of these problems could not be ultimately solved unless investigated in a thoroughly scientific manner.

In criticising the plant pathologists it should not be forgotten that most of them are for the greater part autodidacts. Until recent times there were no places where scientific phytopathology was taught. In Germany it was only the

University of Munich, in which von Tubeuf has been and is still teaching the subject. In Austria, Hecke has been giving lectures for some years. In the United States there has been much progress in this line, due, no doubt, to the fact that plant diseases are of greater importance here than in any other country. As the number of chairs in phytopathology in our institutions of learning increases, however, the relation between scientific botany and phytopathology will become more and more intimate.

Among the factors which favor unusual ravages by vegetable and animal parasites, I wish to mention the rapid development of agriculture by way of growing the same varieties or races over vast areas, the great fertility of the previously uncultivated soils, which often induced people to crop the soil and neglect rotation, and lastly the favorable climatic conditions, which not only favor the cultural plants but also their parasites.

One of the oldest problems of phytopathology is the smut-problem. Since ancient times smuts have been among the most important plagues of our cereals, and long before we knew the cause of these diseases people tried to control them. But rational measures of control could not be developed before the cause of the disease was known. Julius Kühn succeeded in clearing up the life-history of the stinking smut. This was the first distinct step in advance, but here, unfortunately, progress ceased for some time, principally because of the lack of knowledge concerning the taxonomy of the smut-fungi. All loose smuts of oats, wheat, barley, and the close smuts of oats and barley were united under the single species *Ustilago carbo.* This prevented the investigations of the biology of the smuts, and it was not until the fact was demonstrated that various species of smuts were concerned that the way was opened for the proper investigation of the biology and subsequently also of the control of the parasite.

The development of our knowledge of the smuts was due to the biological facts demonstrated by Brefeld and Hecke. They discovered that infection takes place through the flowers. This fact pointed out the way of control. The problem was to kill one organism, the smut-fungus, within another organism, the grain seed, without doing damage to the latter. Jensen by his empirical work had demonstrated that such a procedure was possible. The correct method of control, however, could not be worked out because of the lack of knowledge concerning the fundamental scientific facts involved. In order to establish such a firm basis, I, together with my assistant, Riehm, studied the resistance of the smut-fungi to external conditions, primarily to the effects of temperature. When the mycelium was grown in water and other substrata we demonstrated the fact that the thicker-celled mycelium as well as the spores are more resistant to external influences than is the vigorously growing mycelium. However, not only the smut but also the grain is more resistant in the resting period than when germinating. Therefore, we tried to bring the infected grain seed under conditions which cause the fungus to grow and which at the same time do not allow the seed to germinate. We succeeded in doing this by allowing the seeds to remain for about four hours in water at 25-30°C. If one then subjects the seeds to a temperature at which the mycelium is killed but which does not yet induce germination in the grain, it is possible to kill the mycelium in the seed without injuring the latter.

In these investigations the key to the so-called hot water and hot air treatment was found, and it was then only a technical problem to build apparatus with which the desired results could with certainty be realized. For our conditions in Germany this latter problem has also been solved. We have constructed several pieces of apparatus of this sort, and the treatment of grain against loose smut has been introduced on many farms.

But the smut-problem has not been solved for all cases. This is especially true in the case of the stinking smut in the United States. This disease is of the greatest importance in the wheat districts of Idaho. In Germany *Tilletia Tritici* is spread by the seeds and is controlled by seed disinfection. In Idaho it occurs so generally in the soil that disinfection is of no avail. Losses of 25 per cent of the crop are not uncommon. The solution of this problem seems possible only by the breeding of disease-resistant varieties. It is certain that smut-resistant races of wheat exist. The problem is to find these varieties and, in case they are not sufficiently productive, to cross them with other varieties until races which combine the desired characteristics are obtained. In the districts where smut occurs every year it is possible to find these races in an empirical way. But in general it is my opinion that all work of selecting and breeding should be prosecuted along fundamental scientific lines.

It is therefore first of all necessary to determine to what characters the plant owes its disease-resistant qualities. When this has been accomplished it is next necessary to determine to what extent the characters are heritable, that is to say, whether they appear in crosses as dominant or recessive. The great advantage of this method lies in the fact that it makes it possible to recognize resistant races (by the presence of the specific characters to which resistance is due) without infection experiments, which are uncertain owing to the influence of external and unknown conditions.

I have shown to you by this example that in the solution of a single phytopathological problem such diverse branches of botany as taxonomy, biology of the flower, fungus-biology, and inheritance are involved. The following examples will show that in addition other branches of botany are of importance in phytopathology.

In exact phytopathological investigations it is a primary factor that one know the host plants and the parasites in detail. This information must be based upon thorough systematic knowledge. This seems to be very easy in cultivated plants, the species of which are generally well distinguished. Some cases, however, are more complicated. When we want to make studies of cereal rusts, it is not sufficient to know the races of cereals by their agricultural names. We must know to what botanical species they belong; our cultivated wheats, for instance, comprise species of different susceptibilities.

Much more difficult are the systematic relations of the fungi. Many experiments and publications are valueless because the identity of the fungus was not made sure of in every single case. These difficulties are greater in case the fungi in question belong to the *Fungi Imperfecti,* where very often only the name of the genus has been determined, while the species name was simply made from the name of the host. Moreover, the descriptions of these imperfect fungi are often so insufficient that it is impossible to identify the fungi afterwards, especially when they occur on other plants or on a different or unrecognizable substratum. Within a genus that is rich in species there have sometimes been erected so many species that there is no possibility of identification. We find an instance of this in the genus *Fusarium.* Several hundreds of species have been described; which of these are identical has not yet been made clear, and in many cases this may never be possible. We cannot always solve the problem by making use of the exsiccata of the author of the species. Moreover, on one species of host several species of *Fusarium* may be harbored, and the author has often considered them identical. It is further often impossible to find what fungus was the type of the author's description. In such a case the only alternative is a thorough reworking of the taxonomy. How extensive a work this may often involve is instanced by the genus *Fusarium.* To establish the fundamental facts regarding the taxonomy within this genus required four years of work on my part as well as on the part of my assistant, Dr. Wollenweber, who devoted all of his time to the subject.

Even after the establishment of these fundamental facts, only a very small part of the species had been determined, and for another two years Wollenweber has been working up the remaining species. I wish only to point out in addition that there exist more genera of this type: *Botrytis, Gloeosporium,* and *Alternaria* and its relatives.

Modern taxonomy of fungi cannot limit itself to the morphology of the species casually collected. It must have the help of pure cultures on various media, for in artificial culture additional differences show themselves. These differences are not only biological, such as color formation and changes in the culture media, but also morphological, such as the form of the "Fuszellen" or basal cells of species of *Fusarium,* and even gross, as, for instance, differences in form of colonies, etc.

In the first place, artificial culture is of enormous value as it furnishes the proof of the presence or absence of a relation between different forms of fungi. This knowledge not only gives us a better insight into the development of the organism, but also gives us most important information as to the methods of control.

In the identification of bacteria cultural methods are absolutely necessary as these organisms cannot be determined otherwise. The determination of the host and its enemies is not only desirable on the ground given above, but also because it gives us opportunity for ecological observations. A disease occurs only when conditions are favorable to its development, and these conditions are often pointed out by the composition of the flora of the locality, of which my studies upon the dying-out of alder trees in Germany give you a clear proof. In different localities these trees are killed by a fungus, *Valsa oxystoma.* The fungus grows into the wood through wounds, especially where branches or twigs are broken off, and kills out parts of the cambium and the bark. The parts into which it does not penetrate remain alive. There was no doubt about the fungus being the cause of the disease, but there were groups of trees which, though the fungus was present, were not quite killed out, the damage done in these localities being much smaller. I hit upon the correct explanation of this condition through a study of the special character of the flora under the trees. It was a typical flora of pastures, in which occurred specimens of *Iris pseudacorus* and retreating areas of *Carex paniculata.* These two plants are typical inhabitants of the peats, or water borders. It was clear that the locality had been formerly of a peaty character. I could determine that recently the water level had been lowered for the formation of artificial meadows. Without a knowledge of the flora this relation would never have been found, as these meadows were situated behind a chain of hills. The depth of the ditches had changed the water level and prepared the right conditions for an attack of *Valsa oxystoma.*

In another paper I have shown the importance of the work of E. Münch.[1] This work is a model as to the manner in which investigations of plant diseases upon a scientific basis should be prosecuted. And, therefore, I wish to come back in a more detailed way to the work of Münch. The fungous diseases of our trees belong, in general, to the most important diseases, and we yearly lose millions on their account. But we did not know the factors upon which the appearance of such diseases rested until these were demonstrated by the work of Münch. It was known that many fungi attack woody plants under definite conditions. Sometimes closely related species of one genus of hosts behave differently and sometimes only definite tissues are attacked. Lastly these relations vary in different years or seasons in different localities. The difficulty has been that the cause of this variability was sought in the different soil conditions which might have an influence on the constitution of the tissues of the host, in external injuries—such as sunburn or frost, and in the period of development of the fungus. These factors, however, are not of fundamental importance in the question of the production or suppression of a fungous attack.

Münch has proved through numerous experiments that the content of air in the tissues is the determining factor. The greater part of the wood-decaying fungi have a large air requirement and are able to grow only when a maximum of air is furnished. In the first place the content of air is dependent on the quantity of water, and the occurrence of this large class of plant diseases depends upon the water supply. Similarly, the quantity of solid substance may be of influence. Specimens with narrow annual rings are more resistant than those with broad ones, because there is less room for air in the former. The different annual rings of the same wood may be attacked differently, which is supported by the evidence of many observers. Not infrequently do we find tree trunks in which only some annual rings have been infected, or in which the same ring is diseased on one side and healthy on the other. The decayed rings are always the broad ones. The same varieties have a different air content in different localities. In the neighborhood of water sprouts or vigorous branches, the tissues are rich in water and poor in air, and infections very often do not penetrate into such regions. We know now that poorly fed and crippled specimens are likely to be attacked; on the other hand, it seems clear that fruit trees which are richly fed with nitrogen are very susceptible to canker. An abundance of nitrogen induces the development of a very loose tissue, which during drought is more subject to diseases than a firm tissue. We recognize the periodicity in the occurrence of many plant diseases, for we know the fluctuations in the water content of a tree. The air content of the healthy bark of beeches in winter-rest is 19–20 per cent, and diminishes at the time of budding to 11 per cent, rising afterwards. This is correlated with the fact that the canker, which in Europe is caused by *Nectria ditissima,* does its damage from autumn until spring, while this damage ceases during the vegetative period. This was pointed out by Aderhold, who, however, failed to recognize the cause.

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[1] Untersuchungen über Immunität und Krankheitsempfänglichkeit der Holzpflanzen. Naturwiss. Zeitschr. f. Forst- u. Landw. 7: 54–75, 87–114, 129–160. 1909.

If once we know the absolute percentage of air necessary for fungous growth in the different kinds of wood, we may decide through direct investigation whether in certain localities the danger of infection is large or small. We may test the different varieties and try to avoid the danger. By this method the control is not directed against the fungus, but against the conditions which make its growth possible. In other words, we use instead of direct control, measures which prevent the outbreak of epidemic diseases.

You see by this example what an exactly planned scientific investigation may do, and you can recognize the application of these facts to the American conditions. In the irrigated districts the fruit trees have but few die-back diseases due to species of *Valsa* and other fungi. When, however, such diseases occur, you will find the cause in defective irrigation methods, which may be remedied by changing the irrigation system. It is of the greatest importance that the land be irrigated at the time the trees contain less water and plenty of air, and that the next irrigations be made in time to prevent an excessive decrease of the water in the tissues.

Not all fungi, however, are dependent upon the air contained in the wood. This is, for instance, the case with *Armillaria mellea,* where the rhizomorphs bring a sufficient quantity of air into the inner tissues. Whoever has cultivated the fungus artificially knows that after a short time rhizomorphs are formed which grow deep into the medium. But the rhizomorphs are not formed on all kinds of trees and it may be possible that the fungus in these cases depends on the air already in the wood.

Another question of great importance for American conditions is the question whether the growth of bacteria, principally of *Bacillus amylovorus,* is dependent upon the air content of the host or not. These experiments must be supported by thorough physiological investigations. That manner of control which seeks to remove the bacteria by cutting out the branches does not guarantee success for the future. I have been convinced of this in my trip through the United States, where I visited districts in which this control measure was thoroughly carried out.

It may be possible that not only trees, but also herbaceous plants, show relations between fungous growth and air content. I think it must be so for the organisms which cause the wilt diseases and the rhizoctonia disease of the potato, both of which have a high air requirement. On media poor in air these fungi grow only on the surface and absorb very eagerly the oxygen of hydrogen peroxide. The growth of *Rhizoctonia* in the well-aërated peat soil of the Stockton Delta and the forest soil of Germany is more marked in the dry years than in the years when the plants get a sufficient supply of water. In the United States these diseases are wide-spread, principally through the irrigated lands. In my trip I came to the conclusion that these diseases are not to be controlled by fighting the fungi, but by influencing the potato plant. Though caused by a fungus, the production of the conditions favorable to the progress of the disease is attributable to irrigation. In many cases the root system was poorly developed, the different kinds of irrigation showing an influence upon the growth of the underground parts of the plants. We know very little of the conditions of growth of the potato in spite of a few publications on this subject by Müller-Thurgau, De Vries, and Vöchting. Moreover, we know nothing about transpiration and water requirements in these plants or about their ability to form roots, or the factors that influence these processes. It is, therefore, very important that Shantz, of the Department of Agriculture, has actually undertaken the investigation of these problems. Others must follow him as soon as possible to solve these questions for the irrigated lands.

The chemical-physiological side of the phytopathological questions also needs more attention, as has been pointed out recently by me and others in work upon the freezing problem. For a true judgment of the resistance to frost, in the case of cereal diseases, Gossner has apparently found the right way. The earlier stated fact that the cells of small pieces of tissue floating on a sugar solution are less quickly killed by frost than when floating in water, made it probable that the young plant is protected by sugar against frost injury. The investigation of the winter and summer rye shows that the sugar content of the former is several per cent greater than of the latter. The same is the case for frost-susceptible races of wheat. We may thus find out the relative frost resistance of closely related races of plants by determining the sugar content.

But other phases of chemistry are of importance in phytopathological investigations, as, for instance, the chemistry of colloids, which, as Ruhland showed in his work, is of great value. The microchemical reactions are also of great importance. We know today that cork formation in the potato is a protection against bacterial invasion. I could show by using the reaction of Tisson that the deposition of cork in the cell walls near the places of infection occurs earlier than the formation of cork plates.

Of special interest is the physiology of inheritance. In this lecture I wish merely to emphasize that the inheritance of the unit characters and their behavior in the next generation is one of the fundamentals of breeding resistant races.

Finally, I must speak of anatomy. The necessity of the examination of series of sections oblige the pathologist to make use of the latest discoveries in histology. It is by way of anatomy that we shall approach the problem of leaf-roll of the potato. Onemjer has shown that the sieve tubes, which have the function of providing the plant with albumen, are destroyed in the leaf-rolling plants, similar symptoms occurring in plants which suffer from other diseases only when the plants are nearly dead. In leaf-rolling plants, however, we find these changes from the very beginning, and we may use them in diagnosis. Anatomy, likewise, points out relations between external disease symptoms and inner changes of structure. For instance, the three inner diseases of the potato, leaf-roll, wilt, and bacterial ring disease, have distinguishable anatomical characters; the leaf-roll is a disease of the phloem; wilt, of the secondary wood vessels; and bacterial ring, of the spiral vessels. A thorough anatomical knowledge is of primary importance in all investigations concerning the inner structure of healthy and diseased plants, the formation of excretions and tyloses, and the different ways of recovery.

I hope that it has been possible for me to show you that phytopathology has many fundamental relations to scientific botany, and that it further presents many important problems for scientific investigation which deserve attention from the botanical departments of universities.

Should I have succeeded hereby in winning new friends to phytopathology in this sense it would be a source of genuine satisfaction and pleasure to me.